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Comparison of Analog R-F Photonic Links Using a Variety of Linearized Electro-Optic Modulators

by

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The potential applications of high dynamic range analog r-f photonic links include antenna remoting, photonic-coupled phased-array antennas, and cable-television transmission. This paper compares the results obtained with a number of different modulator types and link configurations and gives recent experimental results. Further details on the analysis and results for some of the schemes can be found in a review paper that will appear later this year [Ref 1].

The dynamic range of a r-f link is defined as the ratio between the output signal level and the noise level at the point where an undesired intermodulation product just emerges from the noise. The undesired product may be the third-order two-tone intermodulation product (which would likely fall within the passband of even a narrow-band link) or a simple harmonic in the case of a broadband link. High dynamic range may be achieved by (1) reducing the intermodulation products through linearization and (2) reducing the noise level.

In our comparison, we assumed representative values for the components of a simple r-f photonic link, given in Table I, and then used numerical calculations to find the distortion products and the resulting dynamic range, harmonic content, small-signal gain, and noise figure for the overall link. Numerical integration is necessary since the transfer functions of some modulators do not allow closed-form solutions. We have assumed a specific bandwidth, 1 Hz, for comparisons, rather than express the resulting dynamic range in dB/Hz$^{2/3}$ since the dynamic ranges for some configurations do not vary with a simple power of the bandwidth, and in most cases the exact optimization of the dynamic range depends on all the numerical values assumed in the link. Hence the link results for different values of the parameters are easily recalculated, but not easily scaled. This problem is also treated in Ref. 1.

Table II lists the results obtained for links using Mach-Zehnder modulators (MZM) and directional coupler modulators (DCM) in various configurations. This includes links using (1) a MZM biased to zero even harmonics, (2) two MZM's in parallel optically (but with unequal optical drives), biased as in (1) and modulated out of phase at different r-f levels so that the third-order two tone modulation (IMD) exactly cancels, but the signals do not, (3) three MZM's in parallel with the same strategy as (2), but canceling the IMD to higher order, (4) two MZM's in series optically, not biased to cancel even harmonics, but biased and driven to minimize IMD, (5) a simple DCM biased to zero the second harmonic, (6) a simple DCM biased to minimize IMD, but exhibiting a strong second harmonic, (7) a DCM followed by a d-c bias section (DCB), with both biased to minimize second harmonic and IMD, (8) a DCM followed by two DCB's, with the same strategy as (7), but IMD and second harmonic cancel to higher order.

All modulators have the same half-wave voltage (V_π for MZM's) or crossover voltage (V_s for DCM's) to make the comparison. The parameters varied to maximize dynamic range and minimize harmonics are: the r-f and optical splitting ratios, and the d-c biases applied to the modulator or bias sections. Since all schemes use cancellation in some form, it is not surprising that the link performance depends very critically on the exact values of the parameters, sometimes requiring stabilization of a parameter to better than 0.01%. Schemes that employ only d-c voltages as variables rather that optical or r-f splits are likely to be more practical.

In addition to configurations to reduce IMD, we can also consider ways to reduce the noise level. A lower RIN (and likely more expensive) laser reduces one component of the noise. Shot noise can be reduced by lowering the average transmission of the modulator. This idea was originally proposed for the simple MZM by shifting the bias toward the extinction point. This reduces signal, IMD *and* shot noise. Unfortunately, the signal goes to zero at the same bias (V_π) as the IMD, and the second harmonic is greatly increased. This idea works much better for the DCM, since the signal does not go to zero at the bias where the IMD goes to zero. Case (6) in Table II illustrates this mode of operation.

Others have suggested that the shot noise can be reduced by biasing a simple MZM at its usual $V_\pi/2$ point and then reducing the "carrier" by optical means (interference or filtering). Unfortunately, this does not work, even in principle, because photonic links are *intensity* modulated, not *amplitude* modulated. Reducing the "carrier" lowers the shot noise, but greatly increases harmonic and intermodulation distortion. Such a scheme will work, however, if true optical amplitude modulation is used, for example, by biasing an MZM to its V_π point, where the output is double-sideband, suppressed carrier optical amplitude modulation. Unfortunately, heterodyne detection is now required to recover the signal rather than simple square-law detection. The performance of this link is given in line (9) of Table II. A 10 mW local oscillator laser and the same RIN as Table I was assumed. Heterodyne detection is required even if carrier were re-inserted to yield ordinary amplitude modulation instead of DSSC. Homodyne detection with either optical AM or DSSC yields the same IMD, but a large second harmonic.

Table I

Parameter	Value
Laser Power	100 mW
Laser RIN	-165 dB
Optical Loss	-10 dB
Mod. Sensitivity	10 V
Mod Impedance	50 Ohm
Det. Responsivity	0.7 A/W
Det. Load Res	50 Ohm
Noise Bandwidth	1 Hz

No electronic preamps or postamps are used.

Table II

Mod. Type	Dyn. R.	Gain	NF
(1) 1xMZM	109.9	-25.2	38
(2) 2xMZM par.	129.7	-36	48.8
(3) 3xMZM par.	134.9	-41.7	54.6
(4) 2xMZM ser.	135.3*	-32.7	37.5
(5) 1xDCM	109.4	-24.8	38
(6) 1xDCM min IMD	135.4*	-31.9	36.7
(7) DCM+1DCB	129.5	-31.7	42.9
(8) DCM+2DCB	129.4	-30.5	43.3
(9) 1xMZM AM het.	115.4	-19.2	35.9

All values in dB
* Second harmonic dynamic range is less.

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(1) W. B. Bridges and J. H. Schaffner, "Distortion in Linearized Electro-Optic Modulators," Special Joint Issue on Microwave and MM-Wave Photonics, J. Lightwave Tech. vol. 13, and IEEE Trans. Microwave Theory and Tech., vol. 43, September 1995, to be published.